Project X & Associated Beams

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Short Baseline Neutrino Workshop

May 12, 2011

Outline

- Role of Project X
- Project X Reference Design
- Beam Configurations
- Project Status and Timeline

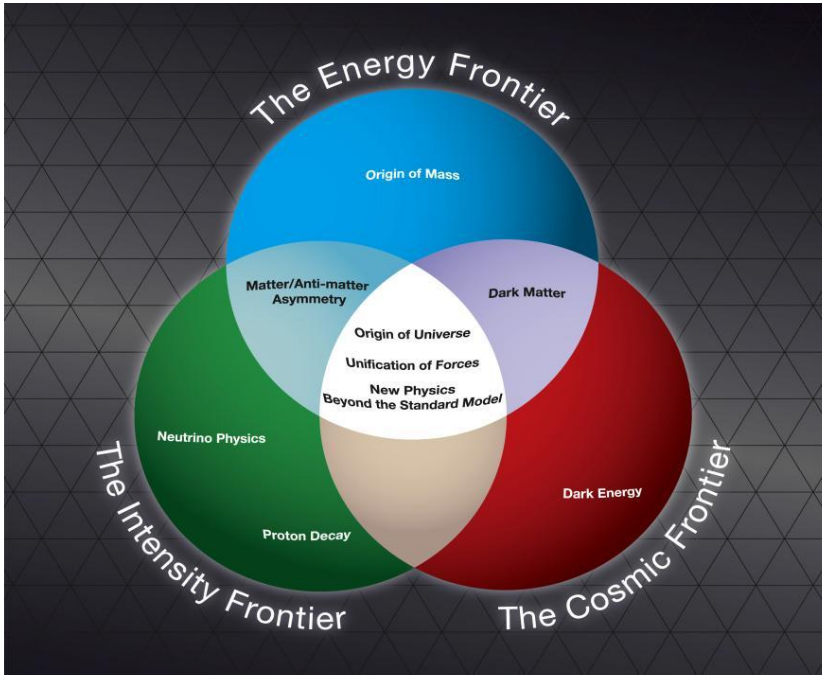
Project X website: http://projectx.fnal.gov

Fermilab Strategic Plan

Fermilab is the sole remaining U.S. laboratory providing facilities in support of accelerator-based Elementary Particle Physics. Fermilab is fully aligned with the strategy for U.S. EPP developed by HEPAP/P5.

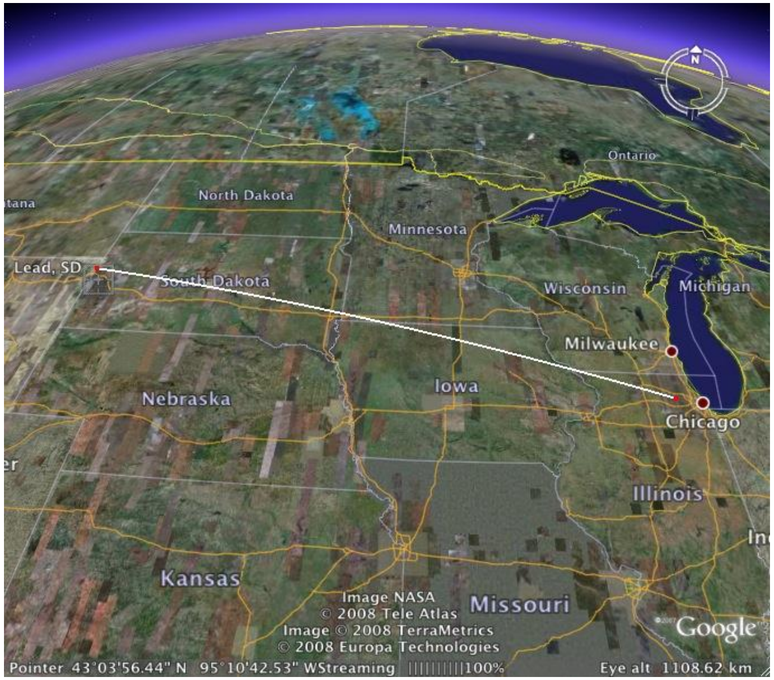
⇒ ***The Fermilab strategy is to mount a world-leading program at the <u>intensity frontier</u>, while using this program as a bridge to an <u>energy frontier</u> facility beyond LHC in the longer term.***

Project X is the key element of this strategy



Mission Elements

- A neutrino beam for long baseline neutrino oscillation experiments
  - 2 MW proton source at 60-120 GeV

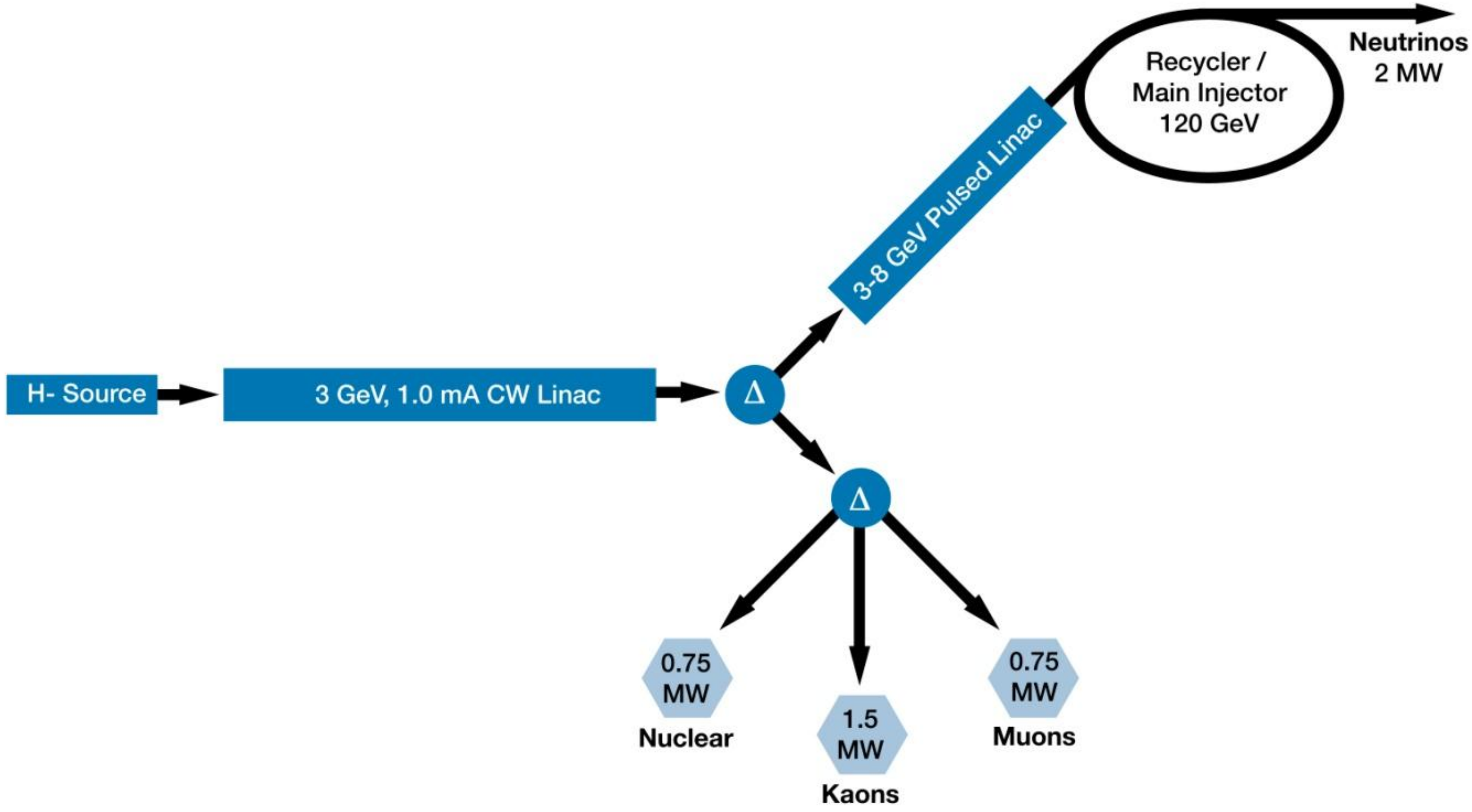


- High intensity, low energy protons for kaon, muon, and neutrino based precision experiments
  - Operations simultaneous with the neutrino program
- A path toward a muon source for possible future Neutrino Factory and/or a Muon Collider
  - Requires ~4 MW at ~5-15 GeV
- Possible missions beyond EPP
  - Standard Model Tests with nuclei and energy applications

Concept Evolution

- Three Project X configurations have been developed, in response to limitations identified at each step:
  - Initial Configuration-1 (IC-1)
    - 8 GeV pulsed linac + Recycler/MI
    - Fully capable of supporting neutrino mission
    - Limited capabilities for rare processes
  - Initial Configuration-2 (IC-2)
    - 2 GeV CW linac + 2-8 GeV RCS + Recycler/MI
    - Fully capable of supporting neutrino mission
    - 2 GeV too low for rare processes (Kaons)
    - Ineffective platform for Neutrino Factory or Muon Collider
  - Reference Design
    - 3 GeV CW linac + 3-8 pulsed linac + Recycler/MI
    - Ameliorates above deficiencies

Reference Design



Reference Design Capabilities

- 3 GeV CW superconducting H- linac with 1 mA average beam current.
  - Flexible provision for variable beam structures to multiple users
    - CW at time scales >1 μsec, 10% DF at <1 μsec
  - Supports rare processes programs at 3 GeV
  - Provision for 1 GeV extraction for nuclear energy program
- 3-8 GeV pulsed linac capable of delivering 300 kW at 8 GeV
  - Supports the neutrino program
  - Establishes a path toward a muon based facility
- Upgrades to the Recycler and Main Injector to provide ≥ 2 MW to the neutrino production target at 60-120 GeV.

⇒ **Utilization of a CW linac creates a facility that is unique in the world, with performance that cannot be matched in a synchrotron-based facility.**

Functional Requirements

Requirement	Description	Value
L1	Delivered Beam Energy, maximum	3 GeV (kinetic)
L2	Delivered Beam Power at 3 GeV	3 MW
L3	Average Beam Current (averaged over >1 μsec)	1 mA
L4	Maximum Beam Current (sustained for <1 μsec)	5 mA
L5	The 3 GeV linac must be capable of delivering correctly formatted beam to a pulsed linac, for acceleration to 8 GeV	
L6	Charge delivered to pulsed linac	26 mA-msec in < 0.75 sec
L7	Maximum Bunch Intensity	1.9×10^{8}
L8	Minimum Bunch Spacing	6.2 nsec (1/162.5 MHz)
L9	Bunch Length	<50 psec (full-width half max)
L10	Bunch Pattern	Programmable
L11	RF Duty Factor	100% (CW)
L12	RF Frequency	162.5 MHz and harmonics thereof
L13	3 GeV Beam Split	Three-way
P1	Maximum Beam Energy	8 GeV
P2	The 3-8 GeV pulsed linac must be capable of delivering correctly formatted beam for injection into the Recycler Ring (or Main Injector).	
P3	Charge to fill Main Injector/cycle	26 mA-msec in <0.75 sec
P4	Maximum beam power delivered to 8 GeV	300 kW
P5	Duty Factor (initial)	< 4%

Project X Functional Requirements

Requirement	Description	Value
M1	Delivered Beam Energy, maximum	120 GeV
M2	Delivered Beam Energy, minimum	60 GeV
M3	Minimum Injection Energy	6 GeV
M4	Beam Power (60-120 GeV)	> 2 MW
M5	Beam Particles	Protons
M6	Beam Intensity	1.6 x 10^{14} protons per pulse
M7	Beam Pulse Length	~10 μsec
M8	Bunches per Pulse	~550
M9	Bunch Spacing	18.8 nsec (1/53.1 MHz)
M10	Bunch Length	<2 nsec (fullwidth half max)
M11	Pulse Repetition Rate (120 GeV)	1.2 sec
M12	Pulse Repetition Rate (60 GeV)	0.75 sec
M13	Max Momentum Spread at extraction	2 x 10^{-3}
I1	The 3 GeV and neutrino programs must operate simultaneously	
I2	Residual Activation from Uncontrolled Beam Loss in areas requiring hands on maintenance.	<20 mrem/hour (average) <100 mrem/hour (peak) @ 1 ft
I3	Scheduled Maintenance Weeks/Year	8
I4	3 GeV Linac Operational Reliability	90%
I5	60-120 GeV Operational Reliability	85%
I6	Facility Lifetime	40 years
U1	Provisions should be made to support an upgrade of the CW linac to support an average current of 4 mA.	
U2	Provisions should be made to support an upgrade of the Main Injector to a delivered beam power of ~4 MW at 120 GeV.	
U3	Provisions should be made to deliver CW proton beams as low as 1 GeV.	
U4	Provision should be made to support an upgrade to the CW linac such that it can accelerate Protons.	
U5	Provisions should be made to support an upgrade of the pulsed linac to support a duty factor or 10%.	
U6	Provisions should be made to support an upgrade of the CW linac to a 3.1 nsec bunch spacing.	

Pulsed Linac

- The Reference Design utilizes a superconducting pulsed linac for acceleration from 3 to 8 GeV
- ILC style cavities and cryomodules
  - 1.3 GHZ, β=1.0
  - 28 cryomodules (@ 25 MV/m)
- ILC style rf system
  - 5 MW klystron
  - Up to four cryomodules per rf source
- Must deliver 26 mA-msec to the Recycler every 0.75 sec. Options:
  - 1 mA x 4.4 msec pulses at 10 Hz
    - Six pulses required to load Recycler/Main Injector
  - 1 mA x 26 msec pulses at 10 Hz
    - One pulse required to load Main Injector

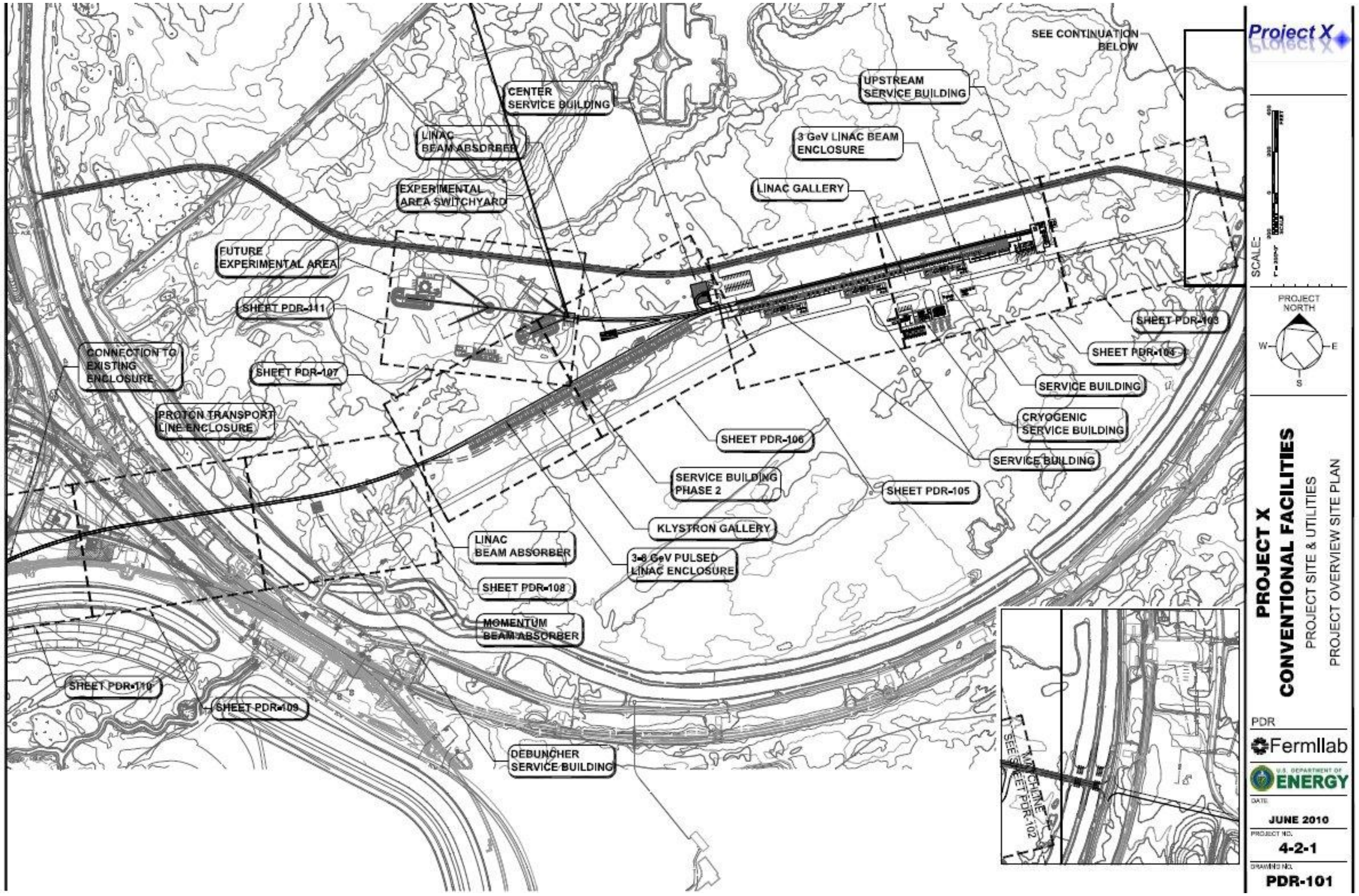
Project X

Performance Goals

Linac		
Particle Type	H^-	
Beam Kinetic Energy	3.0	GeV
Average Beam Current	1	mA
Linac pulse rate	CW	
Beam Power	3000	kW
Beam Power to 3 GeV program	2870	kW
Pulsed Linac		
Particle Type	H^-	
Beam Kinetic Energy	8.0	GeV
Pulse rate	10	Hz
Pulse Width	4.3	msec
Cycles to MI	6	
Particles per cycle to MI	2.6×10^{13}	
Beam Power to 8 GeV	340	kW
Main Injector/Recycler		
Beam Kinetic Energy (maximum)	120	GeV
Cycle time	1.4	sec
Particles per cycle	1.6×10^{14}	
Beam Power at 120 GeV	2200	kW

simultaneous

Siting


SEE CONTINUATION BELOW
CENTER SERVICE BUILDING
UPSTREAM SERVICE BUILDING
3 GeV LINAC BEAM ENCLOSURE
LINAC BEAM ABSORBER
LINAC GALLERY
EXPERIMENTAL AREA SWITCHYARD
FUTURE EXPERIMENTAL AREA
SHEET PDR-111
SHEET PDR-103
SHEET PDR-104
CONNECTION TO EXISTING ENCLOSURE
SHEET PDR-107
SERVICE BUILDING
PROTON TRANSPORT LINE ENCLOSURE
CRYOGENIC SERVICE BUILDING
SHEET PDR-106
SERVICE BUILDING
SERVICE BUILDING PHASE 2
SHEET PDR-105
KLYSTRON GALLERY
LINAC BEAM ABSORBER
3-8 GeV PULSED LINAC ENCLOSURE
SHEET PDR-108
MOMENTUM BEAM ABSORBER
SHEET PDR-110
SHEET PDR-109
DEBUNCHER SERVICE BUILDING
MATCHLINE SEE SHEET PDR-102
Project X
SCALE:
PROJECT NORTH
W
E
S
PROJECT X
CONVENTIONAL FACILITIES
PROJECT SITE & UTILITIES
PROJECT OVERVIEW SITE PLAN
PDR
Fermilab
U.S. DEPARTMENT OF ENERGY
DATE
JUNE 2010
PROJECT NO.
4-2-1
DRAWING NO.
PDR-101

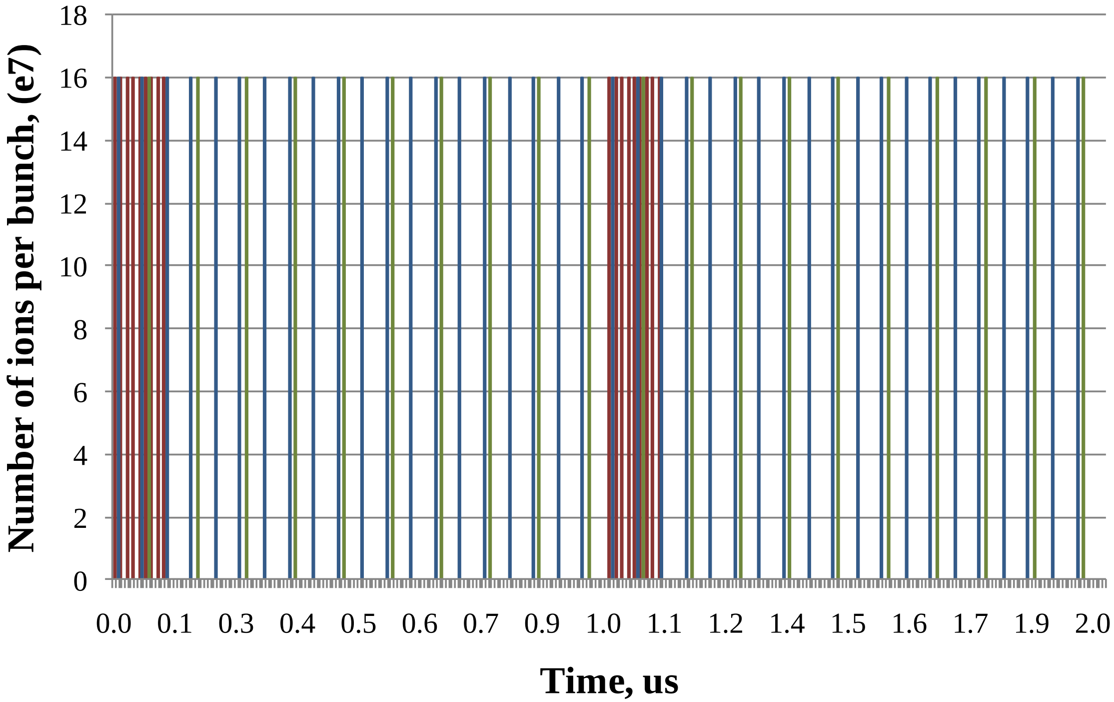
Beam Configurations
3 GeV Operating Scenario

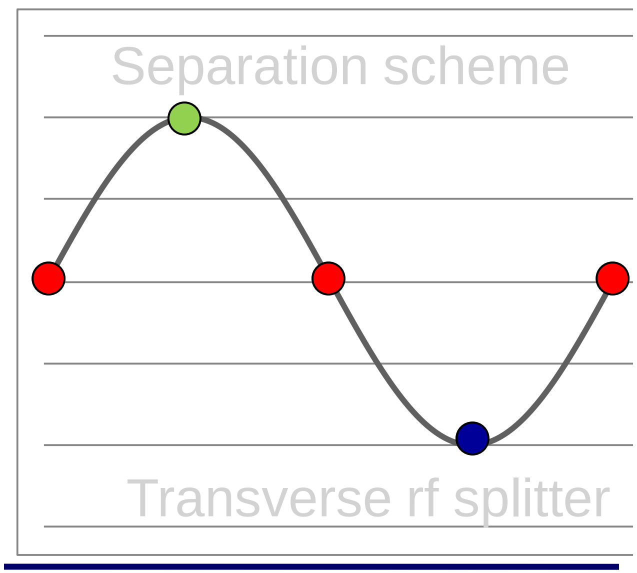
1 μsec period at 3 GeV

Muon pulses (16e7) 81.25 MHz, 100 nsec @ 1MHz	700 kW
Kaon pulses (16e7) 20.3 MHz	1540 kW
Nuclear pulses (16e7) 10.15 MHz	770 kW

Ion source and RFQ operate at 4.2 mA

75% of bunches are chopped @ 2.5 MeV ⇒ maintain 1 mA over 1 μsec





Beam Configurations
Low Energy Neutrinos

- CW linac naturally produced a high duty factor beam
  - Low duty factor can be created utilizing the chopper, resulting in a beam power of 3 MW × DF
  - ⇒ **Creating a high power/low duty factor beam will require an accumulator ring**

- Requirements (as I currently understand them):
  - Beam Energy 3-8 GeV
  - Beam power 400 kW
  - Duty Factor $<1 \times 10^{-3}$
  - Bunch structure not required

Beam Configurations
Low Energy Neutrinos

- Accumulator Ring Concepts

Accumulation Ring	A			B	
Energy	3	GeV		3	GeV
Circumference	200	m		200	m
Injection Current	1	mA		1	mA
Injection Time	1	ms		0.2	ms
Np	6.0E+12			1.2E+12	
Injected Turns	1500			300	
Extraction Pulse	0.67	μsec		0.67	μsec
Cycle Time	7.5	msec		1.5	msec
Duty Factor	8.9E-05			4.4E-04	
Average Current	0.13	mA		0.13	mA
Beam Power	400	kW		400	kW
Normalized Emittance (95%)	40	π mm-mr		40	π mm-mr
Bunching Factor	0.5			0.5	
Laslett Tune Shift	-0.01			0.00	

- Issues
  - Injection
  - Extraction

Status and Timeline

- Pre-conceptual design and R&D activities are well supported
  - Reference Design Report released fall 2010
  - Substantial R&D efforts on
    - sc accelerating structures
    - linac front end and chopper
    - rf sources
    - H- injection
- Approval of CD-0 (“Mission Need”) is under discussion with DOE
  - DOE-sponsored Intensity Frontier Physics Workshop being planned for October

Status and Timeline

- Working timeline

CD-0	FY2012	Mission Need
CD-1	FY2013	Alternative Selection and Cost Range
CD-2	FY2014	Performance Baseline
CD-3	FY2016	Start of Construction
CD-4	FY2021	Start of Operations, Project Complete

Collaboration

- A multi-institutional collaboration has been established to execute the Project X RD&D Program.
  - Organized as a "national project with international participation"
    - Fermilab as lead laboratory
    - International participation established via bi-lateral MOUs.
  - Collaboration MOUs for the RD&D phase outlines basic goals, and the means of organizing and executing the work. Signatories:

ANL	ORNL/SNS	BARC/Mumbai
BNL	MSU	IUAC/Delhi
Cornell	TJNAF	RRCAT/Indore
Fermilab	SLAC	VECC/Kolkata
LBNL	ILC/ART	

- Initial discussions have taken place on execution of the construction phase.

Summary

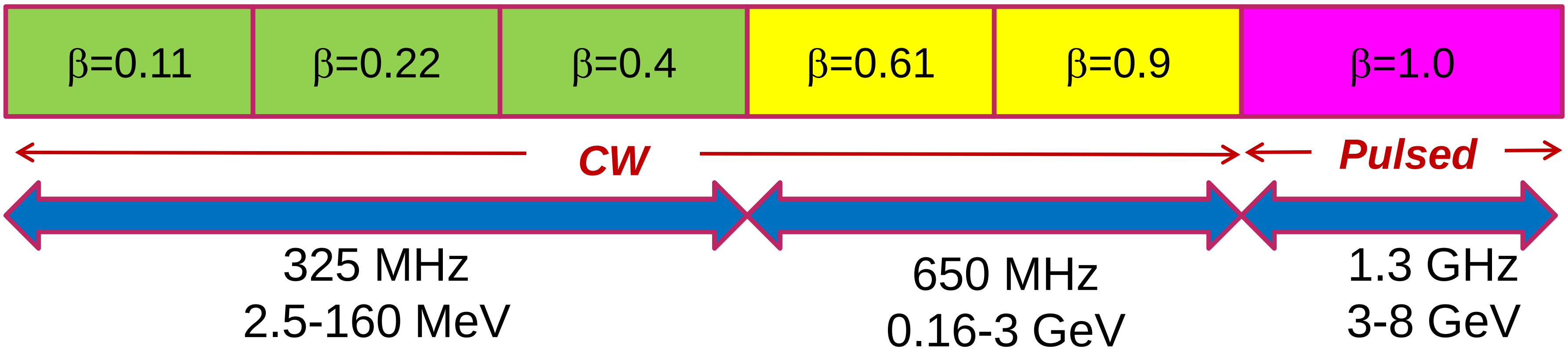
- Project X is central to Fermilab's strategy for development of the accelerator complex over the coming decade
- A Reference Design has been developed that would support a world-leading Intensity Frontier program at Fermilab over several decades:
  - 5 MW of total beam power available
    - 3 MW to the rare processes program
    - 2 MW to the neutrino program over 60-120 GeV
  - Flexible provision for variable beam formats to multiple users
  - Concepts for supporting short baseline neutrinos identified
- The CW linac is unique for this application, and offers capabilities that would be hard/impossible to duplicate in a synchrotron
- R&D program underway with very significant investment in srf infrastructure and development
- Project X could be constructed over the period ~2016 – 2020
  - Will be constructed as a national project with international participation

Backup

R&D Program

- The primary elements of the R&D program include:
  - Development of a wide-band chopper
    - Capable of removing bunches in arbitrary patterns at a 162.5 MHz bunch rate
  - Development of an H- injection system
    - Require between 4.4 – 26 msec injection period, depending on pulsed linac operating scenario
  - Superconducting rf development
    - Includes six different cavity types at three different frequencies
    - Emphasis is on Q_0, rather than high gradient
      - Typically 1.5E10, 15 MV/m (CW)
      - 1.0E10, 25 MV/m (pulsed)
    - Includes appropriate rf sources
    - Includes development of partners
- Goal is to complete R&D phase by 2015

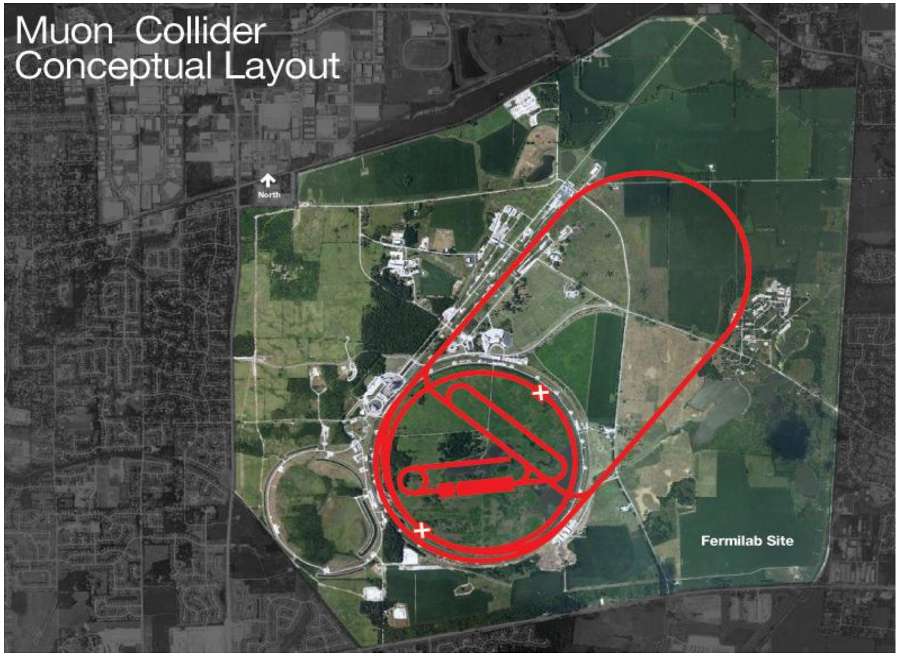
SRF Linac
Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
SSR0 (β_G=0.11)	325	2.5-10	18 /18/1	SSR, solenoid
SSR1 (β_G=0.22)	325	10-42	20/20/ 2	SSR, solenoid
SSR2 (β_G=0.4)	325	42-160	40/20/4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-460	36 /24/6	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	460-3000	160/40/20	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

Joint PX/NF/MC Strategy

- Project X shares many features with the proton driver required for a Neutrino Factory or Muon Collider
  - NF and MC require ~4 MW @ 10± 5 GeV
  - Primary issues are related to beam “format”
    - NF wants proton beam on target consolidated in a few bunches; Muon Collider requires single bunch
  - Project X linac is not capable of delivering this format



⇒ It is inevitable that a new ring(s) will be required to produce the correct beam format for targeting.

Accelerator Requirements:
Rare Processes

	Proton Energy (kinetic)	Beam Power	Beam Timing
Rare Muon decays	2-3 GeV	>500 kW	1 kHz – 160 MHz
(g-2) measurement	8 GeV	20-50 kW	30- 100 Hz.
Rare Kaon decays	2.6 – 4 GeV	>500 kW	20 – 160 MHz. (<50 psec pings)
Precision K^0 studies	2.6 – 3 GeV	> 100 μA (internal target)	20 – 160 MHz. (<50 psec pings)
Neutron and exotic nuclei EDMs	1.5-2.5 GeV	>500 kW	> 100 Hz